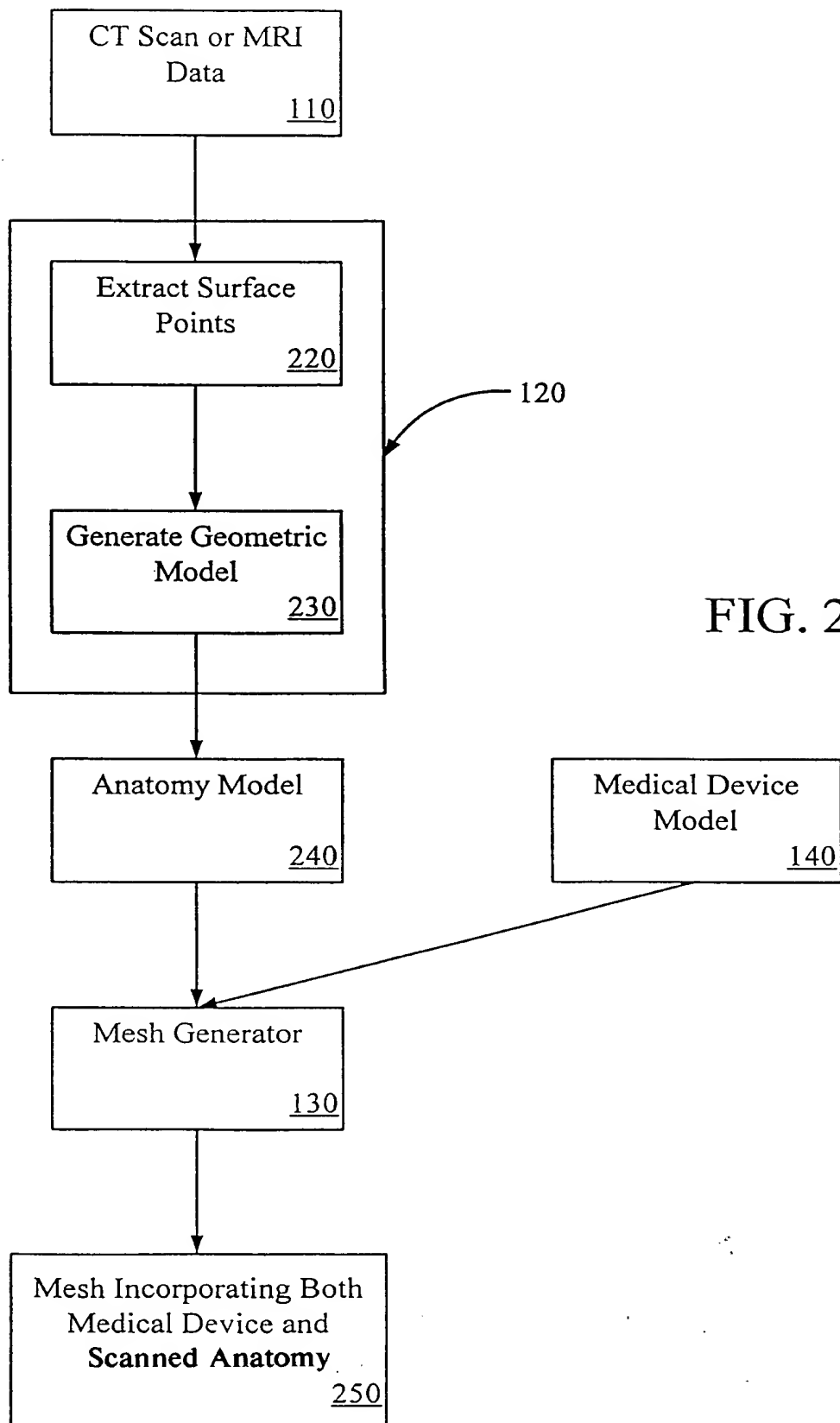


FIG. 1



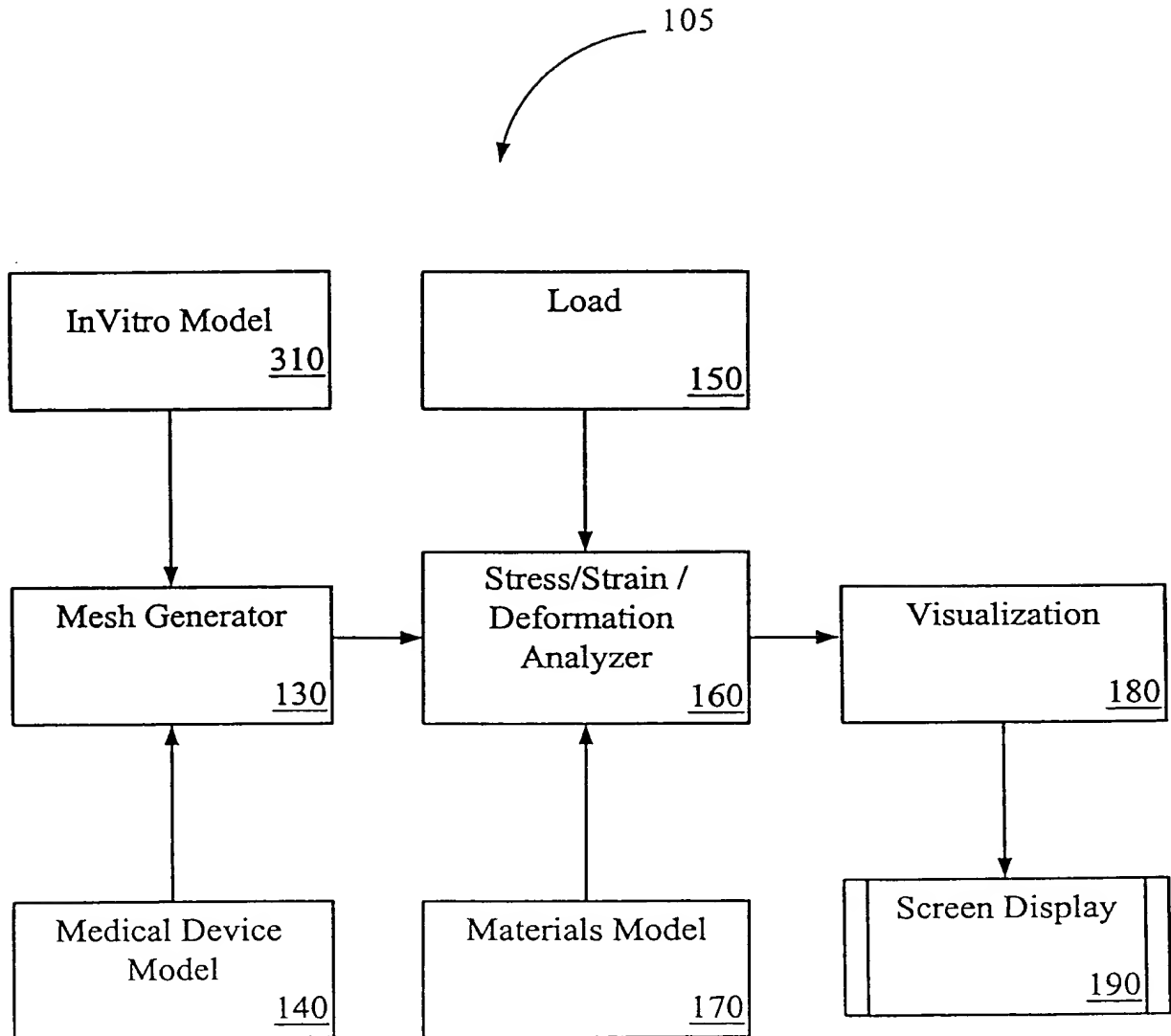


FIG. 3

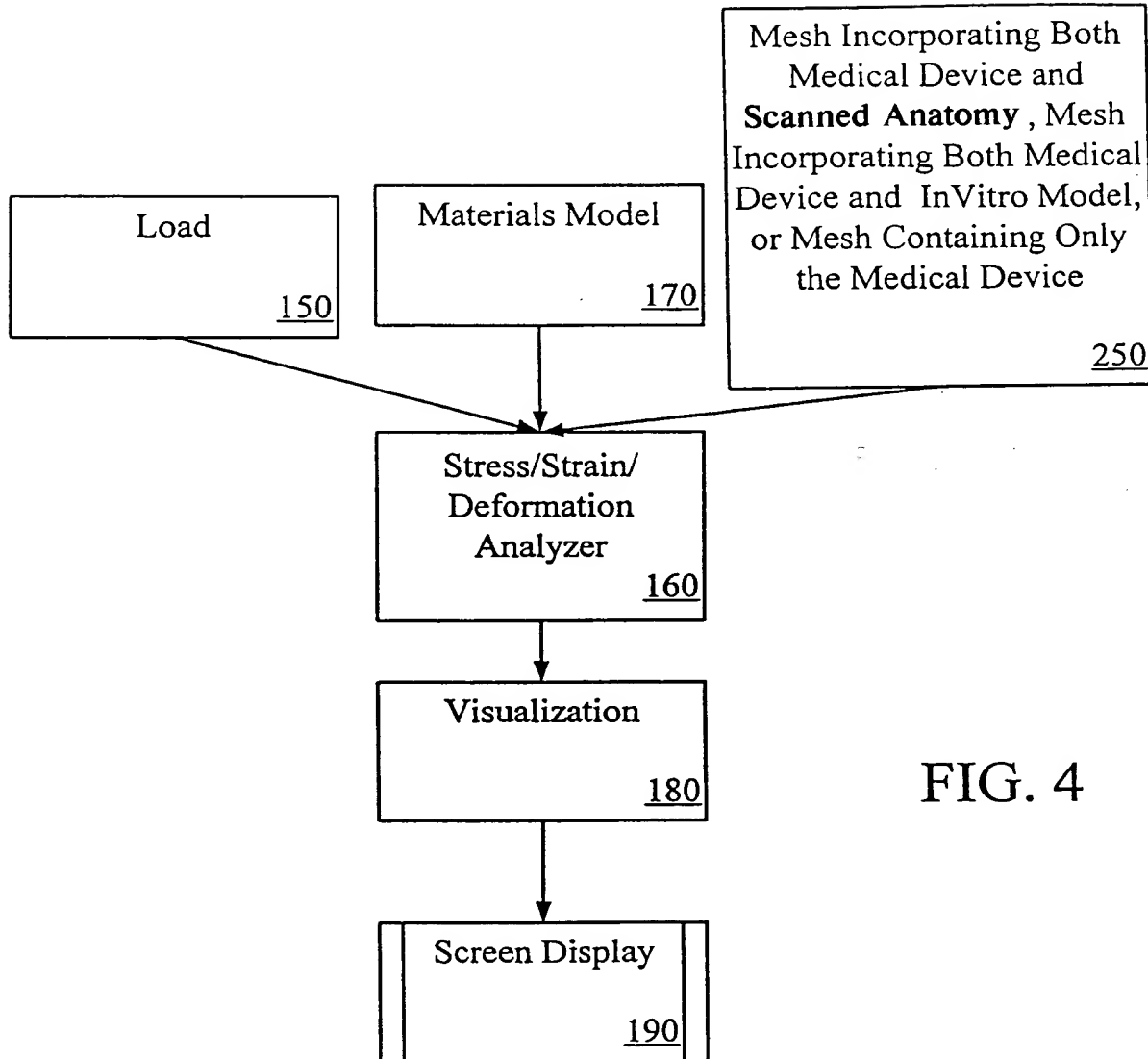


FIG. 4

FIG. 5A

Line Command

```

1  c *** Slotted Tube Integrated Stent Design Simulation: istent.run ****
2  c
3  c ----- parameter settings -----
4  c
5  c .... inike=1 => make nike file; inike=0 => make dyna file
6  c .... imodel = 0 => full 3 segment model with interconnects
7  c           = 1 => 3-crown segment only
8  c           = 2 => 6-crown segment only
9  c           = 3 => 12-crown segment only
10 c .... isym = 0 => full 360 deg model
11 c           = 1 => symmetric model
12 c .... isim_mode: type of simulation
13 c           = 1: => radial force to R_f = X% R_0, restoring stress mat'l
14 c           = 2: => flat plate force, restoring stress mat'l
15 c           = 3: => predelivery compression, loading stress mat'l
16 c           = 4: => initial expansion
17 c           = 5: => frequency analysis
18 c .... refine = X => add X elements via mseq in each direction
19 c           of the cross section
20 c
21 parameter inike 1 ;
22 parameter imodel 0 ;
23 parameter isym 0 ;
24 parameter isim_mode 4 ;
25 parameter refine 2 ;
26 c
27 para Tighten [0.9]; c helps 'tighten' or stiffen spline
28 c range (0.5,1) (probably should not change)
29 c
30 c ----- parameter settings -----
31 c
32 c .... ===== design parameters =====
33 c
34 c Note: Adjust specified OD for each segment considering the wall
35 c thickness for that segment so that ID's match in a consistent
36 c way for the tube blank from which they were cut.
37 c
38 c Upper segment --- 3 crowns
39 c Middle segment -- 6 crowns

```

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FIG. 5B

Line	Command
40	c Lower segment --- 12 crowns (conical)
41	c
42	c Parameters for 3-crown segment
43	c
44	para
45	RCyl3 [.5*2/25.4]
46	dCIA3 [-.00] c delta of center of inner arc for 3 crown segment (-:0)
47	dCOA3 [0] c delta of center of outer arc for 3 crown segment (0:+)
48	CW3 [.007] c Circumferential width of segments for 3 crowns
49	RW3 [.005] c Radial width for 3 crowns
50	NRA3 [.0095] c normal radius of smaller cylinders (arcs)
51	c for 3 crowns
52	Ht3 [0.224] c distance from center of upper arcs
53	c to center of lower arcs for 3 crowns
54	NLegEl3 [12]; c number of elements along the leg
55	
56	c
57	c Parameters for 6-crown segment
58	c
59	para
60	RCyl6 [.5*2/25.4] c outside radius for 6 crown segment
61	dCIA6 [0] c delta of center of inner (smaller) arc for 6 crown segment(-:0)
62	dCOA6 [0.002] c delta of center of outer (larger) arc for 6 crown segment (0:+)
63	CW6 [.009] c Circumferential width of segments for 6 crowns
64	RW6 [.009] c Radial width for 6 crowns
65	NRA6 [.0105] c normal radius of smaller cylinders (arcs)
66	c for 6 crowns
67	Ht6 [.115] c distance from center of upper arcs
68	c to center of lower arcs for 6 crowns
69	NLegEl6 [12]; c number of elements along the leg
70	
71	c
72	c Parameters for 12-crown segment
73	c
74	para
75	dCIA12 [0] c delta of center of inner arc for 12 crown segment (-:0)

FIG. 5C

Line	Command	
76	dCOA12 [0]	c delta of center of outer arc for 12 crown segment (0:+))
77	CW12 [.005]	c Circumferential width of segments for 12 crowns
78	RW12 [.008]	c Radial width for 12 crowns
79	NRA12 [.006]	c normal radius of smaller cylinders (arcs)
80		c for 12 crowns
81	Ht12 [.050]	c distance from center of upper arcs
82		c to center of lower arcs for 12 crowns
83		c (measured along the leg, not necessarily in
84		c the z direction)
85		c first outside radius for 12 crown segment (near other segments)
86	RCyl12_1 [.5*2/25.4 - (.016-%RW12)]	
87		c second outside radius for 12 crown segment (bottom)
88	RCY112_2 [.5*1.4/25.4 - (.016-%RW12)]	
89	c	
90	NLegEl12 [10];	c number of elements along the leg
91		
92	c	
93	c Interconnects	
94	c	
95		
96	c	
97	c Upper interconnects	
98	c	
99	para HIUp [.02]	c height of interconnect
100	FRUp [.005]	c fillet radius for blend
101	ICWUp [.006]	c circumferential width
102	IRWUp3 [.005]	c radial width at 3-crown end
103	IRWUp6 [.006];	c radial width at 6-crown end
104		
105	c	
106	c S-interconnects	
107	c	
108	para SIVer [.01]	c vertical distance between upper or lower arc centers
109		c also the distance from the vertical mid-line to
110		c the first arc center
111	SIHor [.010]	c horizontal distance between upper two or
112		c lower two arc centers
113	SIr [.004]	c arc radius

FIG. 5D

```

Line  Command
114      SIrO [%SIr+%ICWUp/2] c outer radius
115      SIrI [%SIr-%ICWUp/2]; c inner radius
116
117      c
118      c Lower interconnects
119      c
120      para HILr  [.031]  c height of interconnect
121      FRLr  [.010]  c fillet radius for blend
122      ICWLr  [.007]  c circumferential width
123      IRWLr6 [.005]  c radial width at 6-crown end
124      IRWLr12 [.005]; c radial width at 12-crown end
125
126      c

127      c .... ===== design parameters =====
128      c
129      c .... set cylinder ID & OD for compression
130      c
131      if (%isim_mode.le.3) then
132      parameter ricompcyl
133          [1.1*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
134      parameter rocompcyl
135          [1.4*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
136      c
137      c .... set cylinder ID & OD for expansion
138      c
139      elseif (%isim_mode.eq.4) then
140      parameter ricompcyl
141          [0.95*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
142      parameter rocompcyl
143          [0.7*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
144      endif
145      c
146      c Materials assignments
147      c
148      parameter matst12 3 ;
149      parameter matst6 4 ;
150      parameter matst3 5 ;

```


FIG. 5E

```
Line  Command
148  parameter mat126 6 ;
149  parameter mati63 7 ;
150  c
151  c
152  if (%isim_mode.eq.1) then
153      echo *** Radial Force Simulation ***
154  elseif (%isim_mode.eq.2) then
155      echo *** Flat Plate Force Simulation ***
156  elseif (%isim_mode.eq.3) then
157      echo *** Predelivery Compression Simulation ***
158  elseif (%isim_mode.eq.4) then
159      echo *** Initial Expansion Simulation ***
160  elseif (%isim_mode.eq.5) then
161      echo *** Natural Frequency Analysis ***
162  else
163      echo !!! ERROR: illegal isim_mode !!!
164      interrupt
165  endif
166  c
167  c ----- analysis options -----
168  title stent initial expansion simulation
169  c
170  c *** DYNA3D Analysis Options ***
171  c
172  if (%inike.eq.0) then
173      echo Making DYNA3D input file
174      dyna3d
175      dynaopts
176      term 5.0e-5
177      plti 1.e-6
178      prti 5.0e-6
179  c
180  c .... DR options
181  c
182      itrax 500
183      tolrx 1.0e-2
184      drdb
185  c
186  c .... thermal effects option - temp from load curve 1
```

FIG. 5F

Line	Command
187	c
188	teo 1
189	c
190	tssf 0.0
191	c
192	c print initial time step size
193	c
194	c prtflg 1
195	c
196	c turn off (0) or on (1) SAND database flag
197	c
198	edsdf 0
199	c
200	nrest 90000
201	nrunr 95000 ;
202	c
203	c DYNA3D discrete nodes impacting surface - stent to cyl
204	c * one side (180 deg) *
205	c
206	sid 1 dni
207	c sfif
208	c mfif
209	pnlts 1.0e-0
210	pnltm 1.0e-0
211	;
212	c
213	c DYNA3D discrete nodes impacting surface - stent to cyl
214	c * opposite side *
215	c
216	c sid 2 dni
217	c sfif
218	c mfif
219	c pnlts 1.0e-4
220	c pnltm 1.0e-4
221	c ;
222	c
223	c end DYNA3D commands
224	c
225	endif

Line	Command
226	c
227	c
228	c *** NIKE3D Analysis Options ***
229	c
230	if(%inike.eq.1) then
231	echo Making NIKE3D input file . . .
232	nike3d
233	nikeopts
234	nstep 5
235	delt 0.2
236	anal stat
237	c
238	c step tol of 1e-8 seems OK for predel compression
239	c
240	if(%isim_mode.eq.1.or.%isim_mode.eq.2) then
241	dctol -1.0e-8
242	elseif(%isim_mode.eq.3) then
243	dctol -1.0e-6
244	endif
245	c
246	c max iterations per stiffness reform
247	c
248	nibsr 20
249	c
250	c max stiffness reforms per step
251	c
252	msrf 20 ;
253	c
254	c temperatures follow load curve 1
255	c ** manually add tref=1.0 on matl 2 control card cols 26-35 **
256	c
257	teo 1
258	if(%isim_mode.eq.1.or.%isim_mode.eq.2) then
259	iprt 1
260	elseif(%isim_mode.eq.3.or.%isim_mode.eq.4) then
261	iprt 25
262	endif
263	iplt 1
264	nsbrr 1

FIG. 5G

```
Line  Command
265      stifcore 1
266      bfgscore
267      bwmo new
268      echo Bandwidth minimization ACTIVATED with "NEW" option
269      c
270      c element constitutive data incore
271      c
272      bfor 10
273      sfor 10
274      bef 11
275      c
276      c .... linear solver
277      c
278      lsolver fissle
279      c
280      c .... solid element stent contact surface
281      c
282      sid 1 sv
283      c
284      if (%isim_mode.eq.1) then
285      c
286      c
287      pnlt 1.0e-5
288      elseif (%isim_mode.eq.2) then
289      pnlt 0.00001
290      elseif (%isim_mode.eq.3) then
291      c
292      c .... essential to adjust penalty
293      c
294      pnlt 1.0e+4
295      elseif (%isim_mode.eq.4) then
296      pnlt 1.0e-5
297      c iaug 1 ;
298      endif
299      ;
300      c
301      c .... slidesurface between interconnects and segments
302      c
303      sid 2 tied
```

FIG. 5H

```
Line  Command
304      ;
305      c
306      c .... NIKE3D shell geometric stiffness (HL only)
307      c
308      segs 1 ;
309      c
310      c .... end NIKE3D section
311      c
312      endif
313      c
314      c .... symmetry planes
315      c
316      if (%isym.eq.1) then
317      c
318      c .... Symmetric Model
319      c      theta=-60 and +60 symmetry to remove rigid body modes
320      c
321      c plane 1
322      c      0.0 0.0 0.0
323      c      [-sin(60)] [-cos(60)] 0.0
324      c      0.0005 symm ;
325      c plane 2
326      c      0.0 0.0 0.0
327      c      [-sin(60)] [cos(60)] 0.0
328      c      0.0005 symm ;
329      c
330      else
331      c
332      c .... symmetry planes to remove rigid body modes for full model
333      c
334      plane 1
335      0.0 0.0 0.0
336      1.0 0.0 0.0
337      .0005 symm ;
338      plane 2
339      0.0 0.0 0.0
340      0.0 1.0 0.0
341      .0005 symm ;
342      c plane 3
```

FIG. 5I

```
Line Command
343 c 0.0 0.0 0.0
344 c 0.0 0.0 TBD
345 c .0005 symm ;
346 endif
347 c
348 c
349 if (%inike.eq.0) then
350 c
351 c .... Load Curves for DYNA3D **ADD DR FLAG TO INPUT FILE **
352 c
353 if (%isim_mode.eq.1) then
354 c
355 c .... radial force
356 c
357 lcd 1
358 0.000E+00 1.000E+00
359 7.500E-03 2.250E+04
360 1.000E-00 2.250E+04 ;
361 c 1.000E-02 3.000E+04
362 c 1.000E-00 3.000E+04 ;
363 elseif (%isim_mode.eq.2) then
364 c
365 c .... flat plate compression, lcd 1 not used (dummy definition)
366 c
367 quit
368 c
369 elseif (%isim_mode.eq.3) then
370 c
371 c .... predelivery compression strain
372 c
373 lcd 1
374 0.000E+00 1.000E+00
375 1.000E-02 2.008E+05
376 1.000E-00 2.008E+05 ;
377 endif
378 c
379 c .... load curve #2 only used for flat plate compression
380 c
381 lcd 2
```

FIG. 5J

```
Line  Command
382      0.000E+00 0.000E+00
383      1.000E+00 0.000e-00 ;
384  endif
385  c
386  if (%inike.eq.1) then
387  c
388  c .... ***** Load Curves for NIKE3D *****
389  c
390  if (%isim_mode.eq.1) then
391  c
392  c .... radial force
393  c
394  lcd 1
395      0.000E+00 1.000E+00
396      1.000E+00 2.000E+03 ;
397  elseif (%isim_mode.eq.2) then
398  c
399  c .... flat plate compression
400  c
401  lcd 1
402      0.000E+00 1.000E+00
403      1.000E+00 0.000E+00 ;
404  elseif (%isim_mode.eq.3) then
405  c
406  c .... predelivery compression strain
407  c
408  lcd 1
409      0.000E+00 1.000E+00
410      1.000E+00 2.008E+03 ;
411  elseif (%isim_mode.eq.4) then
412  c
413  c .... initial expansion strain
414  c
415  lcd 1
416  c .... thermal load (activate TEO above)
417  c  0.000E+00 1.000E+00
418  c  1.000E+00 -2.008E+04 ;
419  c .... prescribed displacement
420      0.000E+00 0.000E+00
```

FIG. 5K

Line Command

```

421      1.000E+00 1.000E-02 ;
422  endif
423  c
424  c ----- stent parts -----
425  c
426  include irss.tg
427  c
428  c ----- stent materials -----
429  c
430  if (%inike.eq.1) then
431      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
432          include istent.mats_nike_solid
433          echo model for radial force/flat plate analysis
434      elseif (%isim_mode.eq.3) then
435          include istent.mats_compress_nike_solid
436          echo model for predelivery compression strain
437      elseif (%isim_mode.eq.4) then
438          include istent.mats_compress_nike_solid
439          echo model for initial expansion strain
440      endif
441  c
442  elseif (%inike.eq.0) then
443      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
444          include istent.mats_dyna_solid
445          echo model for radial force/flat plate analysis
446      elseif (%isim_mode.eq.3) then
447          include istent.mats_compress_dyna_solid
448          echo model for predelivery compression strain
449      elseif (%isim_mode.eq.4) then
450          include istent.mats_compress_dyna_solid
451          echo model for initial expansion strain
452      endif
453  endif
454  c
455  c .... cylindrical compression for radial force or predelivery compression
456  c
457  if (%isim_mode.eq.1.or.%isim_mode.eq.3.or.%isim_mode.eq.4) then
458  c
459      if (%isym.eq.1) then

```

FIG. 5L

Line	Command
460	include cylinder.parts_sym
461	else
462	include cylinder.parts
463	endif
464	c
465	if (%inike.eq.1) then
466	include cylinder.materials_nike
467	elseif (%inike.eq.0) then
468	include cylinder.materials_dyna
469	endif
470	endif
471	c
472	stp .01
473	merge
474	c

FIG. 5M

```

1  c ***** TPEG Inflatable Proximal Seal Simulation *****
2  c          (seal.run)
3  c          March, 1999
4  c
5  c ----- parameter settings -----
6  c
7  c .... analytical model aorta geometric parameters
8  c    (distortion is 4-lobe)
9  c
10 parameter r_aorta [10.0/25.4] ;
11 parameter thk_aorta [1.0/25.4] ;
12 parameter amp_plaque [0.0/25.4] ;
13 c
14 parameter ro_aorta [%r_aorta+%thk_aorta] ;
15 c
16 c .... -- TPEG Design Parameters --
17 c
18 parameter r_tpeg [10/25.4] ;
19 parameter r_ps [3/25.4] ;
20 parameter l_tpeg 2.0 ;
21 parameter l_flap 0.25 ;
22 c
23 parameter graft_wall_thick [6*0.0013] ;
24 parameter cuff_wall_thick [3*0.0013] ;
25 parameter flap_wall_thick [6*0.0013] ;
26 c
27 c
28 c .... Pressures and load curve assignments
29 c
30 parameter P_hemo 2.32 ;
31 parameter P_cuff 3.0 ;
32 c
33 parameter lc_hemo 1 ;
34 parameter lc_proxcuff 3 ;
35 c
36 c .... TPEG folding simulation parameters
37 c
38 parameter vel_fold 20.0 ;
39 parameter t_fold [0.25/%vel_fold] ;
40 parameter t_init 0.0e-3 ;
41 c
42 c

```

FIG. 6A

```
43 c ----- analysis options -----
44 title sc6.i Seal CT-Solid r_t=10mm r_ps=3mm P_cuff=3.0 990428
45 c
46 c *** DYNA3D Analysis Options ***
47 c
48 dyna3d
49 dynaopts
50 term 6.5e-2
51 plti 5.e-4
52 prti 2.5e-2
53 c
54 c .... DR options
55 c
56 itrax 500
57 c
58 c .... increase DR tol to prevent convergence after compression before expansion
59 c
60 c tolrx 1.0e-6
61 tolrx 1.0e-12
62 drdb
63 c
64 tssf 0.9
65 c
66 c .... turn off (0) or on (1) SAND database flag
67 c
68 edsdf 0
69 c
70 nrest 90000
71 nrunt 5000 ;
72 c
73 c .... symmetry planes on xz and yz planes
74 c
75 plane 1
76 0.0 0.0 0.0
77 1.0 0.0 0.0 0.001 symm ;
78 plane 2
79 0.0 0.0 0.0
80 0.0 1.0 0.0 0.001 symm ;
81 c
82 c .... DYNA3D slidesurface: +x folder cylinder
83 c
84 sid 1 sv
```

FIG. 6B

FIG. 6C

85 pnltts 1.0
86 pnltm 1.0
87 pen
88 ;
89 c
90 c DYNA3D slidesurface: -x folder cylinder
91 c
92 sid 2 sv
93 pnltts 1.0
94 pnltm 1.0
95 pen
96 ;
97 c
98 c
99 c DYNA3D slidesurface: +y folder cylinder
100 c
101 sid 3 sv
102 pnltts 1.0
103 pnltm 1.0
104 pen
105 ;
106 c
107 c DYNA3D slidesurface: -y folder cylinder
108 c
109 sid 4 sv
110 pnltts 1.0
111 pnltm 1.0
112 pen
113 ;
114 c
115 c DYNA3D tpeg to aorta (aorta is master)
116 c
117 sid 5 sv
118 c
119 c solid element aorta
120 c
121 pnltts 0.1
122 pnltm 0.1
123 c
124 c shell element aorta
125 c
126 c pnltts 1.0

FIG. 6D

```

127 c pnltm 1.0
128 pen
129 ;
130 c
131 c .... load curve: hemodynamics ***** ADD DR FLAG TO INPUT FILE *****
132 c
133 lcd 1
134 0.000E+00 0.000E+00
135 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
136 [%t_init+2*%t_fold+2.0e-3] %P_hemo
137 1.000E+00 %P_hemo ;
138 c
139 c .... load curve: channel !! NOT USED !! ***** ADD DR FLAG TO INPUT FILE *****
140 c
141 lcd 2
142 0.000E+00 0.000E+00
143 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
144 [%t_init+2*%t_fold+2.0e-3] 0.000e-00
145 1.000E+00 0.000e-00 ;
146 c
147 c .... load curve: proximal cuff ***** ADD DR FLAG TO INPUT FILE *****
148 c
149 lcd 3
150 0.000E+00 0.000E+00
151 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
152 [%t_init+2*%t_fold+2.0e-3] %P_cuff
153 1.000E+00 %P_cuff ;
154 c
155 c .... load curve for +x folder cylinder motion/velocity
156 c
157 lcd 4
158 0.000E+00 0.000E+00
159 %t_init 0.000E+00
160 [%t_init+1.0E-04] [-%vel_fold]
161 [%t_init+%t_fold] [-%vel_fold]
162 [%t_init+%t_fold+1.0e-3] 0.000E+00
163 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
164 [%t_init+2*%t_fold+2.0e-3] [2.0*%vel_fold]
165 [%t_init+3*%t_fold+2.0e-3] [2.0*%vel_fold]
166 [%t_init+3*%t_fold+3.0e-3] 0.000e+00
167 1.000E+00 0.000E+00 ;
168 c

```

FIG. 6E

```

169 c .... load curve for -x folder cylinder motion
170 c
171 lcd 5
172 0.000E+00          0.000E+00
173 %t_init           0.000E+00
174 [%t_init+1.000E-04] [%vel_fold]
175 [%t_init+%t_fold]   [%vel_fold]
176 [%t_init+%t_fold+1.0e-3] 0.000E+00
177 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
178 [%t_init+2*%t_fold+2.0e-3] [-2.0*%vel_fold]
179 [%t_init+3*%t_fold+2.0e-3] [-2.0*%vel_fold]
180 [%t_init+3*%t_fold+3.0e-3] 0.000e+00
181 1.000E+00          0.000E+00 ;
182 c
183 c .... load curve for +y folder cylinder motion
184 c
185 lcd 6
186 0.000E+00          0.000E+00
187 %t_init           0.000E+00
188 [%t_init+1.000E-04] [-%vel_fold]
189 [%t_init+%t_fold]   [-%vel_fold]
190 [%t_init+%t_fold+1.0e-3] 0.000E+00
191 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
192 [%t_init+2*%t_fold+2.0e-3] [2.0*%vel_fold]
193 [%t_init+3*%t_fold+2.0e-3] [2.0*%vel_fold]
194 [%t_init+3*%t_fold+3.0e-3] 0.000e+00
195 1.000E+00          0.000E+00 ;
196 c
197 c .... load curve for -y folder cylinder velocity
198 c
199 lcd 7
200 0.000E+00          0.000E+00
201 %t_init           0.000E+00
202 [%t_init+1.000E-04] [%vel_fold]
203 [%t_init+%t_fold]   [%vel_fold]
204 [%t_init+%t_fold+1.0e-3] 0.000E+00
205 [%t_init+2*%t_fold+1.0e-3] 0.000e+00
206 [%t_init+2*%t_fold+2.0e-3] [-2.0*%vel_fold]
207 [%t_init+3*%t_fold+2.0e-3] [-2.0*%vel_fold]
208 [%t_init+3*%t_fold+3.0e-3] 0.000e+00
209 1.000E+00          0.000E+00 ;
210 c

```

```
211 c ----- parts and materials -----
212 c
213 c
214 c .... get CT-data meshed aorta; convert cm to inches
215 c
216 cscs [1./2.54]
217 include tpeg.part_ct_aorta3
218 c
219 cscs 1.0
220 c
221 c .... option for analytical aorta model
222 c
223 c include tpeg.part_eq_aorta
224 c
225 include tpeg.part_cuff1
226 include tpeg.part_folder2
227 c
228 include tpeg.materials_dyna
229 c
230 c .... use negative tols to prevent aorta nodes merging w/ folder cylinder
231 c nodes if they coincidently become adjacent
232 c
233 c .... merge nodes within CT aorta part using rather loose tolerance
234 c
235 bptol 1 1 0.01
236 bptol 1 3 -1.0
237 bptol 1 4 -1.0
238 bptol 1 5 -1.0
239 bptol 1 6 -1.0
240 tp .001
241 c
```

FIG. 6F

FIG. 7A

```
1      c
2      c          tpeg.part_ct_aorta3
3      c          April 15, 1999
4      c
5      c ----- Aortic Model for Inflatable TPEG Model -----
6      c          Derived from Patient CT Data
7      c          Outer surface constructed with 0.52 mm offset from inner
8      c
9      c .... this is an aortic mesh file which surrounds the neck of the
10     c          3-D AAA reconstruction with solid elements.
11     c
12     c          This file uses TrueGrid planes, oriented by eye using trial
13     c          and error graphically, to determine an orthonormal section.
14     c          Trick there is to adjust surface until walls of proximal neck section
15     c          are parallel to global z axis. Use rz to rotate screen to find values,
16     c          then use in surface transformation to position CT data for meshing.
17     c
18     c .... import IGES file containing surface data from CT scan
19     c
20     c iges solid1.igs 1 1 mx -18.54 my -16.8    ry 24 rx 22 mz 4.8;
21     c
22     c .... inner surface
23     c
24     c sd 17 sds 9 12;
25     c
26     c .... outer surface
27     c
28     c sd 18 sds 15 16 ;
29     c
30     c sd 201 plan
31         0. 0. 1.5
32         0 0 1
33     c sd 202 plan
34         0. 0. 2.5
35         0 0 1
36     c sd 203 plan
37         0. 0. -2.3
38         0 0 1
39     c sd 204 plan
40         0. 0. 3.3
41         0 0 1
42     c sd 301 cy 0 0 0 0 0 1 1.35
```


43 sd 401 plan
44 0. 0. 0.
45 0. 1. 0.
46 c
47 c adjust mz to position part at cuff on Z-axis;
48 c cuff may be z=[2,2.15]
49 cylinder
50 1 2;
51 1 2 3;
52 1 2 3 4 ;
53 c
54 1.0 1.25
55 0 180.0 360.0
56 -2.3 1.5 2.5 3.3
57 c
58 mseq i 2
59 mseq j 29 29
60 mseq k 20 5 5
61 c
62 c project top and bottom ends of aorta segment onto orthonormal planes
63 c
64 sfi ; ; -2; sd 201
65 sfi ; ; -3; sd 202
66 c
67 c project top of upper neck segment onto orthonormal plane
68 c
69 sfi ; ; -4; sd 204
70 c
71 c project bottom of lower neck segment onto orthonormal plane
72 c after radially expanding bottom ring by delta-r=2.0
73 mbi -1; ; -1; x 2.0
74 mbi -2; ; -1; x 2.0
75 sfi ; ; -1; sd 203
76 c
77 c project inner cylinder surface onto aorta luminal surface
78 c
79 sfi -1; 1 3; 2 3; sd 17
80 sfi -1; 1 3; 3 4; sd 17
81 sfi -1; 1 3; 1 2; sd 17
82 c
83 c project outer cylinder onto aorta outer wall surface
84 c

FIG. 7B

85 sfi -2; 1 3; 2 3; sd 18
 86 sfi -2; 1 3; 3 4; sd 18
 87 sfi -2; 1 3; 1 2; sd 18
 88 c
 89 c project theta=0/360 seam onto a plane to facilitate merging
 90 c
 91 sfi 1 2; -1; ; sd 401
 92 sfi 1 2; -3; ; sd 401
 93 c
 94 c
 95 c ... --- slidesurface definition with TPEG body ---
 96 c
 97 orpt + 0. 0. 3.0
 98 sii -1; 1 3; 3 4; 5 m
 99 c
 100 c +y hemicylinder is material 11; -y is mat 12
 101 c
 102 mti ; 1 2; 2 4 ; 11
 103 mti ; 2 3; 2 4; 12
 104 c
 105 c rigid material for aneurysm sac
 106 c
 107 mti ; 1 3; 1 2; 13
 108 c
 109 c Boundary Conditions
 110 c * fix proximal end only in z
 111 c
 112 bi ; ; -4; dz 1 ;
 113 c
 114 c adjust mz to position aorta at cuff on Z-axis;
 115 c cuff may be z=[2,2.15]
 116 lct 1
 117 mz [1.01*2.54] mx 0.7; ;
 118 lrep 1 ;
 119 endpart
 120 c

FIG. 7C

FIG. 8A

```

1  c ***** Slotted Tube Integrated Stent Design Simulation *****
2  c      (istent.run)
3  c      Stent design analysis & CT-Anatomy simulation
4  c
5  c ----- parameter settings -----
6  c
7  c .... inike=1 => make nike file; inike=0 => make dyna file
8  c .... imodel = 0 => full 3 segment model with interconnects
9  c          = 1 => 3-crown segment only
10 c          = 2 => 6-crown segment only
11 c          = 3 => 12-crown segment only
12 c .... isym = 0 => full 360 deg model
13 c          = 1 => symmetric model
14 c .... isim_mode: type of simulation
15 c          = 1: => radial force to R_f = 80% R_0, restoring stress mat'l
16 c          = 2: => flat plate force, restoring stress mat'l
17 c          = 3: => predelivery compression to 12 F, loading stress mat'l
18 c          = 4: => initial expansion
19 c          = 5: => frequency analysis
20 c          = 6: => anatomy deployment
21 c .... refine = X => add X elements via mseq in each direction
22 c          of the cross section
23 c
24 c !!! warning - only 1st 8 characters of variable unique !!!!
25 c
26 c parameter inike 1 ;
27 c parameter imodel 2 ;
28 c parameter isym 0 ;
29 c parameter isim_mode 6 ;
30 c parameter refine 1 ;
31 c
32 c para Tighten [0.9];    c helps 'tighten' or stiffen spline
33 c          c range (0.5,1) (probably should not change)
34 c
35 c ----- parameter settings -----
36 c
37 c .... ===== design parameters =====
38 c
39 c Note: Adjust specified OD for each segment considering the wall thickness
40 c       for that segment so that ID's match in a consistent way for the
41 c       tube blank from which they were cut.
42 c
43 c Upper segment --- 3 crowns
44 c Middle segment -- 6 crowns
45 c Lower segment --- 12 crowns (could be conical)
46 c
47 c Parameters for 3-crown segment
48 c
49 c para

```

FIG. 8B

50 RCyl3 [29*0.5/25.4]
 51 dCIA3 [-.00] c delta of center of inner arc for 3 crown segment (-:0)
 52 dCOA3 [0] c delta of center of outer arc for 3 crown segment (0:+)
 53 CW3 [.020] c Circumferential width of segments for 3 crowns
 54 RW3 [.018] c Radial width for 3 crowns
 55 NRA3 [.0195] c normal radius of smaller cylinders (arcs)
 56 c for 3 crowns
 57 Ht3 [1.048] c distance from center of upper arcs
 58 c to center of lower arcs for 3 crowns
 59 NLegEl3 [12]; c number of elements along the leg
 60 c
 61 c Parameters for 6-crown segment
 62 c
 63 para
 64 RCyl6 [29*0.5/25.4] c outside radius for 6 crown segment
 65 dCIA6 [0] c delta of center of inner (smaller) arc for 6 crown segment (-:0)
 66 dCOA6 [0.005] c delta of center of outer (larger) arc for 6 crown segment (0:+)
 67 CW6 [.020] c Circumferential width of segments for 6 crowns
 68 RW6 [.018] c Radial width for 6 crowns
 69 NRA6 [.0195] c normal radius of smaller cylinders (arcs)
 70 c for 6 crowns
 71 Ht6 [.310] c distance from center of upper arcs
 72 c to center of lower arcs for 6 crowns
 73 NLegEl6 [12]; c number of elements along the leg
 74 c
 75 c Parameters for 12-crown segment
 76 c
 77 para
 78 dCIA12 [0] c delta of center of inner arc for 12 crown segment (-:0)
 79 dCOA12 [0] c delta of center of outer arc for 12 crown segment (0:+)
 80 CW12 [.008] c Circumferential width of segments for 12 crowns
 81 RW12 [.008] c Radial width for 12 crowns
 82 NRA12 [.006] c normal radius of smaller cylinders (arcs)
 83 c for 12 crowns
 84 Ht12 [.164] c distance from center of upper arcs
 85 c to center of lower arcs for 12 crowns
 86 c (measured along the leg, not necessarily in
 87 c the z direction)
 88 c first outside radius for 12 crown segment (near other segments)
 89 RCyl12_1 [22*0.5/25.4]
 90 c second outside radius for 12 crown segment (bottom)
 91 RCYl12_2 [20*0.5/25.4]
 92 c
 93 NLegEl12 [10]; c number of elements along the leg
 94 c
 95 c Interconnects
 96 c
 97 c Upper interconnects
 98 c

FIG. 8C

```

99  para
100 c HIUp [.10] c height of interconnect
101   HIUp [.20] c height of interconnect
102   FRUp [.016] c fillet radius for blend
103   ICWUp [.010] c circumferential width
104   IRWUp3 [.016] c radial width at 3-crown end
105   IRWUp6 [.016]; c radial width at 6-crown end
106 c
107 c S-interconnects
108 c
109 para
110 c SIVer [.03] c vertical distance between upper or lower arc centers
111   SIVer [.06] c vertical distance between upper or lower arc centers
112             c also the distance from the vertical mid-line to
113             c the first arc center
114   SIHor [.0125] c horizontal distance between upper two or
115             c lower two arc centers
116   SIr [.008] c arc radius
117   SIrO [%SIr+%ICWUp/2] c outer radius
118   SIrI [%SIr-%ICWUp/2]; c inner radius
119 c
120 c Lower interconnects
121 para
122 c HILr [.071] c height of interconnect
123   HILr [.142] c height of interconnect
124   FRLr [.016] c fillet radius for blend
125   ICWLR [.016] c circumferential width
126   IRWLR6 [.005] c radial width at 6-crown end
127   IRWLR12 [.005]; c radial width at 12-crown end
128 c
129 c .... ===== design parameters =====
130 c
131 c .... set cylinder ID & OD for compression
132 c
133 if (%isim_mode.le.3.or.%isim_mode.eq.6) then
134   parameter ricompcyl [1.1*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
135   parameter rocompcyl [1.4*max(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)] ;
136 c
137 c .... set cylinder ID & OD for expansion
138 c
139 elseif (%isim_mode.eq.4) then
140   parameter rocompcyl [0.95*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
141   parameter ricompcyl [0.7*(min(%RCyl3,%RCyl6,%RCyl12_1,%RCyl12_2)-%RW6)] ;
142   endif
143 c
144 c Materials assignments
145 c
146 parameter matst12 3 ;
147 parameter matst6 4 ;

```

```
148 parameter matst3 5 ;
149 parameter mat126 6 ;
150 parameter mati63 7 ;
151 c
152 if (%isim_mode.eq.1) then
153     echo *** Radial Force Simulation ***
154 elseif (%isim_mode.eq.2) then
155     echo *** Flat Plate Force Simulation ***
156 elseif (%isim_mode.eq.3) then
157     echo *** Predelivery Compression Simulation ***
158 elseif (%isim_mode.eq.4) then
159     echo *** Initial Expansion Simulation ***
160 elseif (%isim_mode.eq.5) then
161     echo *** Natural Frequency Analysis ***
162 elseif (%isim_mode.eq.6) then
163     echo *** Anatomy Deployment Simulation***
164 else
165     echo !!! ERROR: illegal isim_mode !!!
166     interrupt
167 endif
168 c
169 c ----- analysis options -----
170 title human-size stent anatomy deployment
171 c
172 c *** DYNA3D Analysis Options ***
173 c
174 if (%inike.eq.0) then
175     echo Making DYNA3D input file
176     dyna3d
177     dynaopts
178     term 2.0e-4
179     plti 1.e-4
180     prti 5.0e-6
181 c
182 c .... DR options
183 c
184 c itrx 500
185 c tolrx 1.0e-6
186 c drdb
187 c
188 c .... thermal effects option - temp from load curve 1
189 c
190 if (%isim_mode.ne.5) then
191     teo 1
192 endif
193 c
194 tssf 0.0
195 c
196 c print initial time step size
```

FIG. 8D

```
197 c
198 c prtflg 1
199 c
200 c .... turn off (0) or on (1) SAND database flag
201 c
202 edsdf 0
203 c
204 nrest 90000
205 nrunr 95000 ;
206 c
207 c .... DYNA3D stent to compression cyl
208 c
209 sid 1 dni
210 c sfif
211 c mfif
212 pnltz 1.0e-0
213 pnltm 1.0e-0
214 ;
215 c
216 c .... DYNA3D tied interface to interconnects if multisegment
217 c
218 if (%imodel.eq.0) then
219 sid 2 tied
220 ;
221 endif
222 c
223 c .... end DYNA3D commands
224 c
225 endif
226 c
227 c *** NIKE3D Analysis Options ***
228 c
229 if (%inike.eq.1) then
230 echo Making NIKE3D input file ...
231 nike3d
232 nikeopts
233 c
234 c .... temperatures follow load curve 1
235 c ** manually add tref=1.0 on matl 2 control card cols 26-35 **
236 c
237 teo 1
238 c
239 if (%isim_mode.eq.5) then
240 anal dyn
241 neig 20
242 shift 69
243 iplt 1
244 nsbrr 1
245 stifcore 1
```

FIG. 8E

FIG. 8F

```
246      bfgscore
247      bwmo new
248      c
249      c element constitutive data incore
250      c
251      bfor 10
252      sfor 10
253      bef 11
254      c
255      c .... linear solver
256      c
257      lsolver fissle
258      c
259      elseif (%isim_mode.ne.5) then
260      c
261      c .... time step analysis
262      c
263      nstep 100
264      delt 0.0100
265      anal stat
266      c
267      c .... step tol of 1e-2 is OK for predel compression
268      c
269      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
270      dtol -1.0e-3
271      elseif (%isim_mode.eq.3) then
272      dtol -1.0e-2
273      endif
274      c
275      c .... max iterations per stiffness reform
276      c
277      nibsr 20
278      c
279      c .... max stiffness reforms per step
280      c
281      msrf 20 ;
282      if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
283      iprt 1
284      elseif (%isim_mode.eq.3.or.%isim_mode.eq.4) then
285      iprt 25
286      endif
287      iplt 1
288      nsbrr 1
289      stifcore 1
290      bfgscore
291      bwmo new
292      echo Bandwidth minimization ACTIVATED with "NEW" option
293      c
294      c element constitutive data incore
```


FIG. 8G

```
295 c
296   bfor 10
297   sfor 10
298   bef 11
299 c
300 c .... linear solver
301 c
302   lsolver fissle
303 c
304 c .... solid element stent contact surface
305 c
306   sid 1 sv
307 c
308   if (%isim_mode.eq.1) then
309   c
310   c .... below changed for sharp-edge laser-cut stent
311   c
312   pnlt 1.0e-3
313   elseif (%isim_mode.eq.2) then
314   pnlt 0.01
315   elseif (%isim_mode.eq.3) then
316   c
317   c .... essential to cut penalty for laser-cut stent predel compression
318   c
319   pnlt 0.001
320   elseif (%isim_mode.eq.4) then
321   pnlt 1.0e-3
322   c iaug 1 ;
323   endif
324   ;
325   c
326   c .... end block for time step only analysis
327   c
328   endif
329   c
330   c .... slidesurface between interconnects and segments
331   c
332   sid 2 tied
333   ;
334   c
335   c .... slidesurface between stent and aortic wall
336   c
337   if (%isim_mode.eq.6) then
338   echo *** Add activation time of 0.5 to slidesurface 2 ***
339   sid 3 sv
340   ;
341   endif
342   c
343   c .... NIKE3D shell geometric stiffness (HL only)
```

```

344 * c
345     segs 1 ;
346     c
347     c .... end NIKE3D section
348     c
349     endif
350     c
351     c .... symmetry planes (omit for freq analysis)
352     c
353     if (%isim_mode.ne.5) then
354     if (%isym.eq.1) then
355     c
356     c .... Symmetric Model
357     c
358     c plane 1
359     c 0.0 0.0 0.0
360     c [-sin(60)] [-cos(60)] 0.0
361     c 0.0005 symm ;
362     c plane 2
363     c 0.0 0.0 0.0
364     c [-sin(60)] [cos(60)] 0.0
365     c 0.0005 symm ;
366     c
367     else
368     c
369     c .... symmetry planes to remove rigid body modes for full model
370     c
371     plane 1
372     0.0 0.0 0.0
373     1.0 0.0 0.0
374     .0005 symm ;
375     plane 2
376     0.0 0.0 0.0
377     0.0 1.0 0.0
378     .0005 symm ;
379     endif
380     endif
381     c
382     c
383     if (%inike.eq.0) then
384     c
385     c .... Load Curves for DYNA3D **** ADD DR FLAG TO INPUT FILE ****
386     c
387     if (%isim_mode.eq.1) then
388     c
389     c .... radial force
390     c
391     lcd 1
392     0.000E+00 1.000E+00

```

FIG. 8H

FIG. 8I

```

393      7.500E-03 2.250E+02
394      1.000E-00 2.250E+02 ;
395  elseif (%isim_mode.eq.2) then
396  c
397  c .... flat plate compression, lcd 1 not used (dummy definition)
398  c
399  echo !!! Flat plate not implemented for DYNA3D !!!
400  quit
401  c
402  elseif (%isim_mode.eq.3) then
403  c
404  c .... predelivery compression strain - 0.87 in. dia compressed to 12F
405  c      [check x-displ of stent center node to verify]
406  c
407  lcd 1
408      0.000E+00 1.000E+00
409      1.000E-02 1.008E+03
410      1.000E-00 1.008E+03 ;
411  elseif (%isim_mode.eq.6) then
412  c
413  c .... anatomy deployment
414  c      (LC from radial comp)
415  c
416  lcd 1
417      0.000E+00 1.000E+00
418      7.500E-04 1.000E+03
419      9.000E-04 1.000E+03
420      1.500E-03 1.000E+00
421      1.000E-00 1.000E+00 ;
422  endif
423  c
424  c .... load curve #2 only used for flat plate compression
425  c
426  lcd 2
427      0.000E+00 0.000E+00
428      1.000E+00 0.000E-00 ;
429  endif
430  c
431  if (%inike.eq.1) then
432  c
433  c .... ***** Load Curves for NIKE3D *****
434  c
435  if (%isim_mode.eq.1) then
436  c
437  c .... radial force
438  c
439  lcd 1
440      0.000E+00 1.000E+00
441      1.000E+00 3.000E+02 ;

```

FIG. 8J

```

442 elseif (%isim_mode.eq.2) then
443 c
444 c .... flat plate compression, lcd 1 not used (dummy definition)
445 c
446 lcd 1
447 0.000E+00 1.000E+00
448 1.000E+00 0.000E+00 ;
449 elseif (%isim_mode.eq.3) then
450 c
451 c .... predelivery compression strain - 0.87 in. dia compressed to 12F
452 c [check x-displ of stent center node to verify]
453 c
454 lcd 1
455 0.000E+00 1.000E+00
456 1.000E+00 1.008E+03 ;
457 elseif (%isim_mode.eq.4) then
458 c
459 c .... initial expansion strain - 4/5 mm OD to 15/27 mm OD
460 c [check x-displ of stent center node to verify]
461 c
462 lcd 1
463 c .... thermal load (activate TEO above)
464 0.000E+00 1.000E+00
465 1.000E+00 -1.008E+03 ;
466 c .... prescribed displacement
467 c 0.000E+00 0.000E+00
468 c 1.000E+00 1.000E-01 ;
469 c
470 elseif (%isim_mode.eq.5) then
471 c
472 c .... must define load curve since TEO active even if unused for freq
473 c
474 c .... initial expansion strain - 4/5 mm OD to 15/27 mm OD
475 c [check x-displ of stent center node to verify]
476 c
477 lcd 1
478 c .... thermal load (activate TEO above)
479 0.000E+00 1.000E+00
480 1.000E+00 -1.008E+03 ;
481 elseif (%isim_mode.eq.6) then
482 c
483 c .... anatomy deployment - 0.87 in. dia compressed to 12F
484 c
485 lcd 1
486 0.000E+00 1.000E+00
487 0.500E+00 5.000E+02
488 1.000E+00 1.000E+00 ;
489 endif
490 endif

```

```

491 c
492 c ----- stent parts -----
493 c
494 include irss.tg
495 c
496 c ----- anatomy parts -----
497 c
498 if (%isim_mode.eq.6) then
499 c
500 c .... convert anatomy data from cm to inch units
501 c
502 control
503 csca [1./2.54]
504 c
505 c .... import meshed anatomy data for stent deployment
506 c      (this is an aortic stent)
507 c
508 include tpeg.part_ct_aorta3
509 csca 1.0
510 merge
511 if (%inike.eq.1) then
512 c
513 c .... set material properties for aortic wall
514 c
515 include aorta.materials_nike
516 endif
517 endif
518 c
519 c ----- stent materials -----
520 c
521 if (%inike.eq.1) then
522     if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
523         include istent.mats_nike_solid
524         echo NiTi model for radial force/flat plate analysis
525     elseif (%isim_mode.eq.3) then
526         include istent.mats_compress_nike_solid
527         echo NiTi model for predelivery compression strain
528     elseif (%isim_mode.eq.4) then
529         include istent.mats_compress_nike_solid
530         echo NiTi model for initial expansion strain
531     elseif (%isim_mode.eq.5) then
532         include istent.mats_nike_freq_solid
533         echo NiTi model for frequency analysis
534     elseif (%isim_mode.eq.6) then
535         include istent.mats_nike_solid
536         echo NiTi model for anatomy deployment
537     endif
538 c
539 elseif (%inike.eq.0) then

```

FIG. 8K

FIG. 8L

```

540     if (%isim_mode.eq.1.or.%isim_mode.eq.2) then
541         include istent.mats_dyna_solid
542         echo NiTi model for radial force/flat plate analysis
543     elseif (%isim_mode.eq.3) then
544         include istent.mats_compress_dyna_solid
545         echo NiTi model for predelivery compression strain
546     elseif (%isim_mode.eq.4) then
547         include istent.mats_compress_dyna_solid
548         echo NiTi model for initial expansion strain
549     elseif (%isim_mode.eq.6) then
550         include istent.mats_compress_dyna_solid
551         echo NiTi model for anatomy deployment
552     endif
553 endif
554 c
555 c .... cylindrical compression for radial force or predelivery compression
556 c
557 if (%isim_mode.eq.1.or.%isim_mode.eq.3.or.%isim_mode.eq.4.or.%isim_mode.eq.6) then
558 c
559     if (%isym.eq.1) then
560         include cylinder.parts_sym
561     else
562         include cylinder.parts
563     endif
564 endif
565 c
566 if (%inike.eq.1) then
567     include cylinder.materials_nike
568 elseif (%inike.eq.0) then
569     include cylinder.materials_dyna
570 endif
571 c
572 stp .0001
573 c
574 c .... Constrain stent node(s) in z-direction for time-hist analysis
575 c
576 if (%isim_mode.ne.5) then
577     merge
578 c
579 c .... nset for 3-segment model
580 c nset zconstr = 1 8149 8687 9215 9747 ;
581 c echo ** Bottom 12-crown node list Constrained in Z-translation **
582 c
583 c .... nset for 6-crown only
584 c echo ** Bottom 6-crown node list constrained in z-dir **
585 c nset zconstr = 1 43 97 151 448 ;
586 c b nset zconstr dz 1 ;
587 endif
588 c
  
```

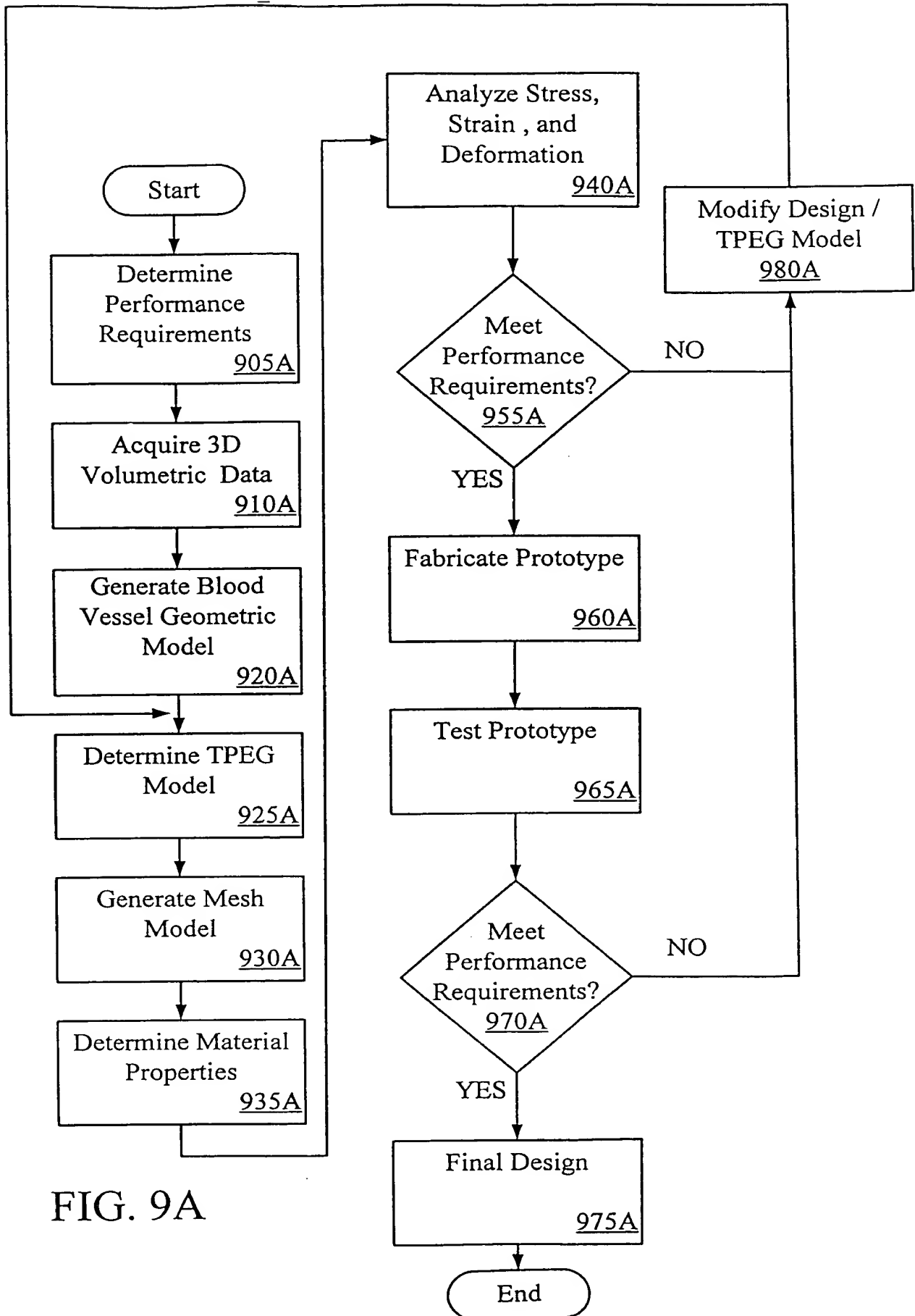


FIG. 9A

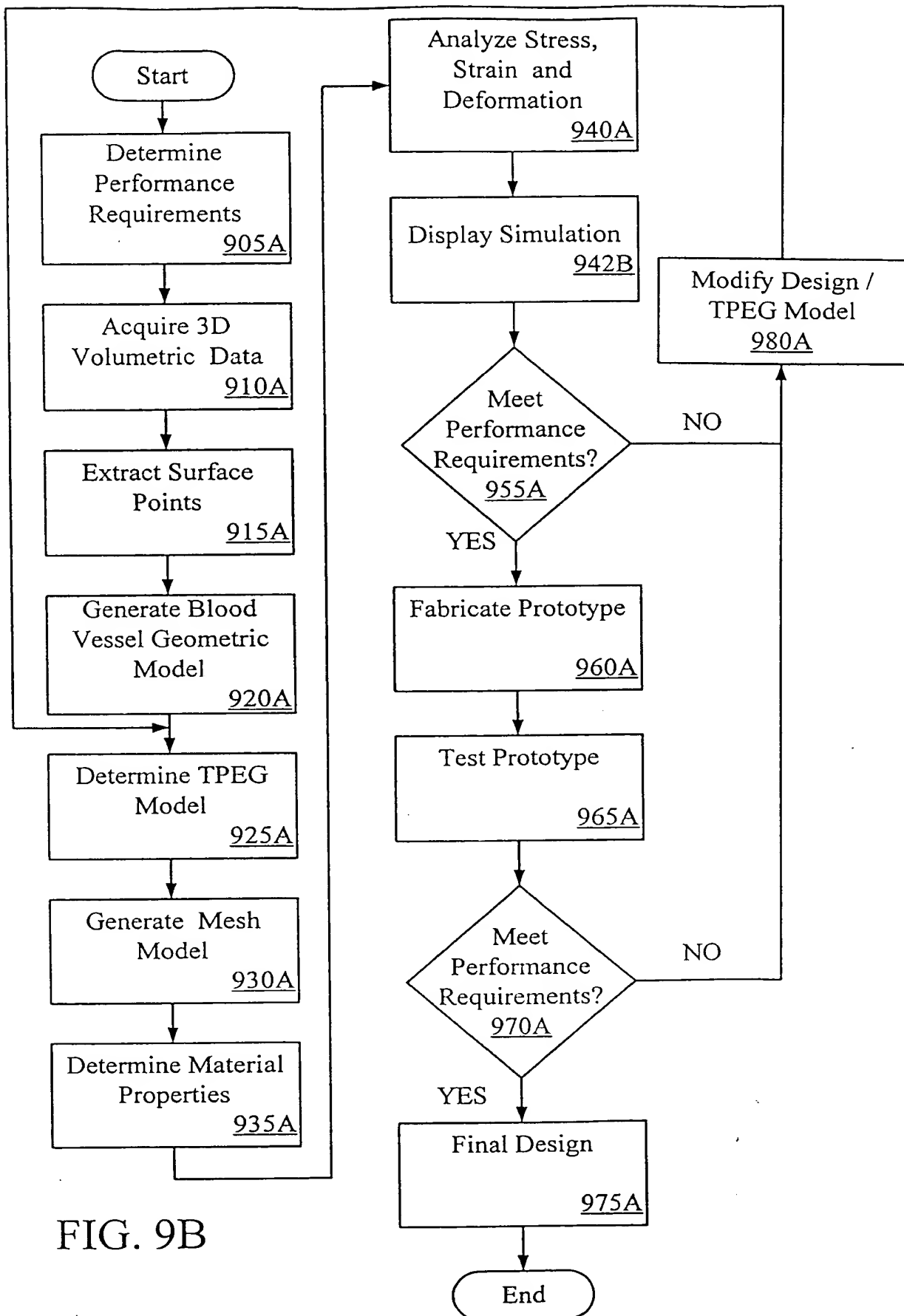


FIG. 9B

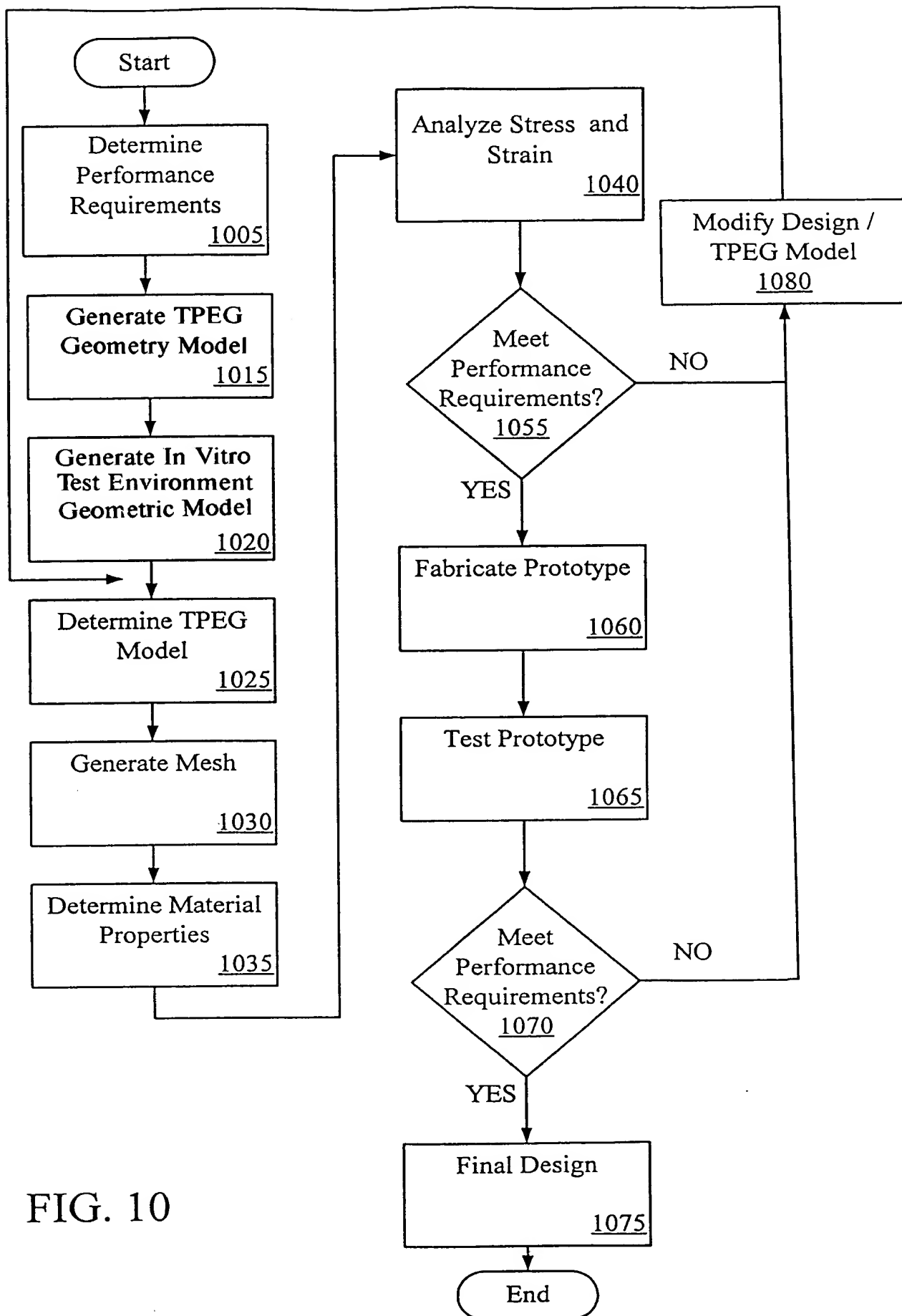


FIG. 10

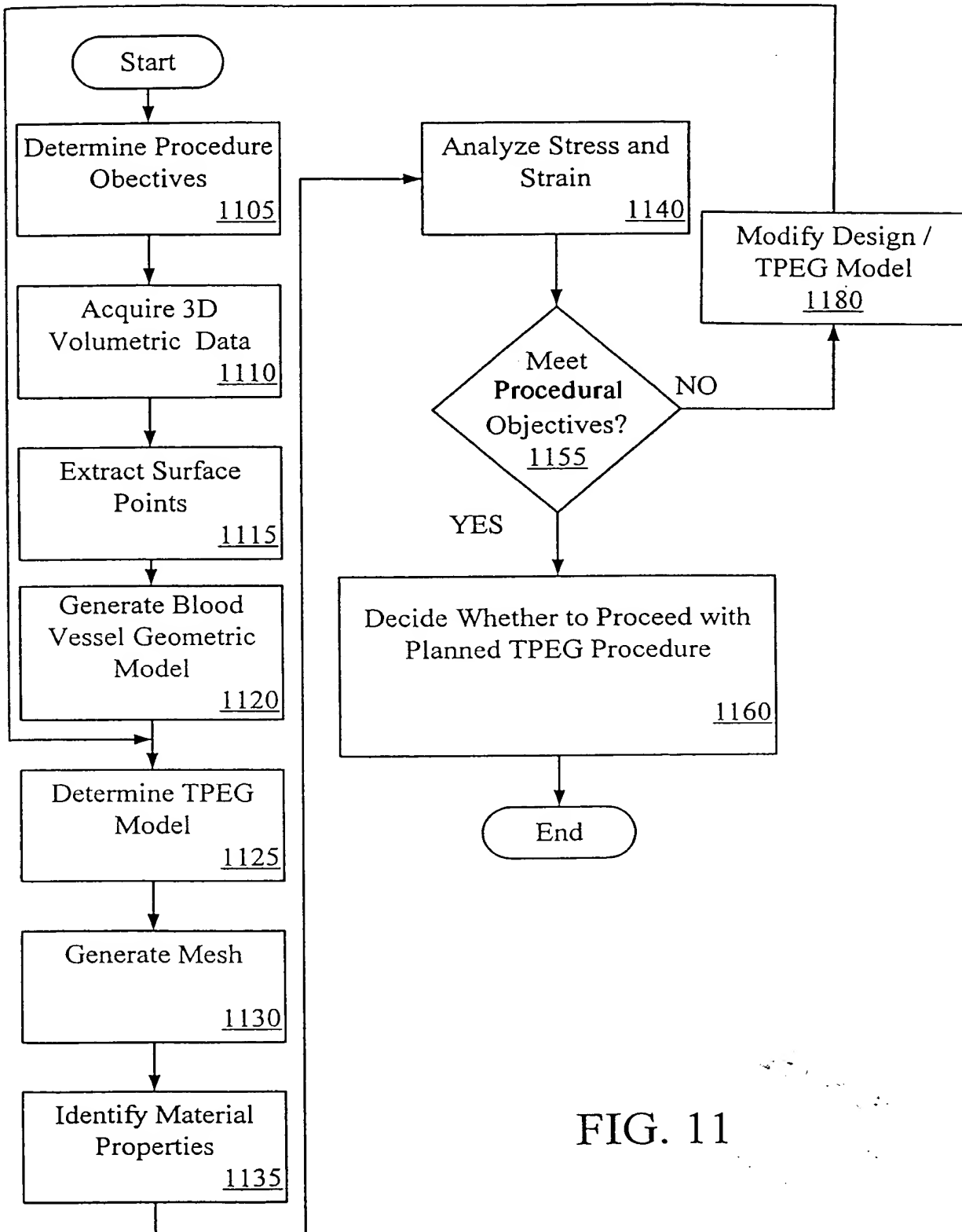


FIG. 11

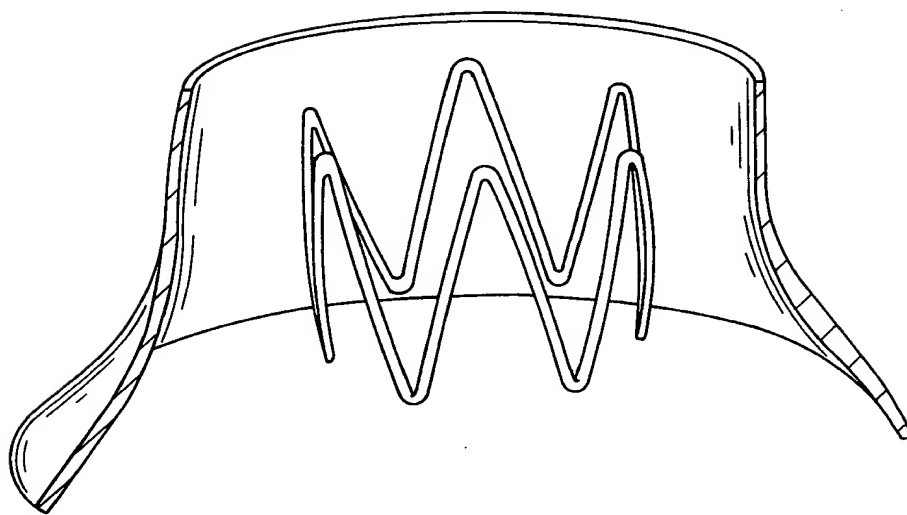


FIG. 12

FIG. 13

